Field Materials Manual Series:

Concrete Foundations, Shotcrete & Specialty Placements

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Course Overview

Course Description

Concrete is extensively used in highway construction for... bridges, tunnels, culverts, and other structures. For these specialized applications, specific material selections and construction procedures are required to ensure long-term performance.

This course covers specialty concrete applications including shotcrete, driven piles, drilled shafts, and protective coatings. These applications require different materials, procedures, and verification methods than typical concrete pavements or deck construction. The course will look at what makes each application unique, how to specify materials, and how to verify quality in the field. This course draws from the Federal Lands Highway Field Materials Manual and is part of a series on highway materials acceptance and testing.

Learning Objectives

Upon successful completion of this course, participants will be able to:

- Understand shotcrete materials, proportioning, and placement procedures
- Specify and verify driven piles (H-piles, concrete-filled pipe, precast concrete, timber, sheet piles)
- Understand drilled shaft construction, casing, mineral slurry, and integrity testing
- Recognize when protective coatings (painting) are required and verify application
- Accept or reject concrete foundations based on field observations and testing

Intended Audience

This course is intended for civil, foundation and structural engineers, as well as construction managers, project engineers, quality assurance personnel, and bridge/structure inspectors responsible for concrete foundation systems, shotcrete, driven piles, and drilled shafts on highway projects.

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Acronym Reference Guide

This glossary lists the acronyms and abbreviations used in this course.

Acronym	Full Name	Context/Usage
AASHTO	American Association of State Highway and Transportation Officials	Sets test methods (T 11, T 99, etc.)
ACI	American Concrete Institute	Concrete design standards (ACI 211.1, etc.)
ASR	Alkali-Silica Reactivity	Durability problem in harsh climates
ASTM	ASTM International	Sets test standards
DEF	Delayed Ettringite Formation	Durability problem from high sulfates
f'c	Compressive Strength of Concrete	Design strength (psi)
f'cr	Required Average Compressive Strength	Must exceed this in testing
FHWA	Federal Highway Administration	U.S. Department of Transportation agency
FLH	Federal Lands Highway	Oversees highway projects on federal lands; issues the Field Materials Manual
FP	Federal Highway Projects	Projects funded and managed under Federal Highway Administration authority; subject to FLH Field Materials Manual requirements
NETTCP	Northeast Transportation Training and Certification Program	Nationally accepted certification for sampling and testing personnel; regional certification standard
NICET	National Institute for Certification in Engineering Technologies	Technician certifications (Level II)
QL-PAY	Quality Level/Payment Statistical Analysis Software	FLH software for comparing contractor vs. inspector test results and determining pay factors
SHA	State Highway Agency	State-level transportation agency; coordinates with FHWA on highway projects
WAQTC	Western Alliance for Quality Transportation Construction	Regional testing standards

Chapter 1

Introduction & Specialty Concrete Applications

1.1 Introduction

Concrete is used in highway infrastructure for more than just pavements and standard bridge decks. Shotcrete, driven piles, drilled shafts, and protective coatings represent specialty concrete applications with unique material requirements, placement procedures, and quality control methods.

This course covers these specialty applications. Engineers will learn shotcrete material specifications and test panel procedures, understand the differences among driven pile types and their inspection requirements, recognize the critical role of mineral slurry and integrity testing in drilled shafts, and understand protective coating systems and application procedures.

Each application shares the fundamental durability principles covered in the Concrete Materials & Mix Design course, but placement and verification methods differ significantly. The course emphasizes that specialty applications demand specialized expertise and rigorous field oversight.

1.2 Summary and Description

Concrete is one of the most widely used building materials in the world and a primary component of many highway structures. It is used in many highway applications such as roadway surfacing, bridges, retaining walls, head walls, culverts, guardrails, anchors, and posts. Concrete is a composite material that consists of a binding medium within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate. In Portland cement concrete, the binder is a mixture of Portland cement and water, with or without admixtures.

The material presented herein will focus primarily on structural concrete and minor concrete as denoted in the Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP). Shotcrete and other topics relating to the construction of structures will also be addressed. Generally, structural concrete is specified in a contract when load analysis (i.e. bridges, culverts, wall and foundations) is required and the total concrete mixture quantity is greater than or equal to 50 yd^3 (38 m^3). Minor concrete is typically specified when load analysis is not required (i.e. headwalls, curb and gutter, sidewalks, waterways) and the total concrete mixture quantity is less than 50 yd^3 (38 m^3). The FP provides requirements for quality construction and materials that include:

- Material Component Requirements
- Concrete Composition, Mixture Proportioning and Mix Design Approval
- Construction and Materials Acceptance

1.3 Linking Specialty Applications to Core Concrete Principles

The concrete used in shotcrete, drilled shafts, and driven piles must meet the same durability requirements as any highway concrete structure. A bridge foundation in Minnesota requires freeze-thaw resistant concrete regardless of whether it is cast-in-place, driven as a precast unit, or installed as a drilled shaft.

However, the methods of achieving durability differ. Shotcrete placement (spray application) poses challenges different from standard vibrated concrete. Drilled shafts face slurry contamination risks that cast concrete does not. Driven piles must withstand driving stresses and dynamic loads during installation. This course focuses on the specialized procedures and quality control methods unique to these applications.

Chapter 2

Concrete Materials Specifications for Specialty Applications

2.1 Concrete Materials Specifications

Concrete is typically composed of the following basic materials:

- Hydraulic cement
- Mineral admixtures (i.e. fly ash, silica fume, ground granulated blast furnace slag)
- Water
- Aggregates (coarse and fine)
- Chemical admixtures (i.e. air entraining, water reducing, set retarding, etc.)
- Fibers

The standard specifications typically used for each of these basic materials are shown in Table 1. Both AASHTO and ASTM standards have been developed for most concrete materials. Table 1 shows both the AASHTO and ASTM materials standards. Although both standards have been listed for ready reference and comparative purposes, their individual requirements may differ in some circumstances. It should be noted that contract specifications will state the standards that are applicable for a given construction project and also may provide additional requirements which supplement the AASHTO/ASTM specifications.

Table 1: Concrete Material Specifications.

Material Component	Test Method
Hydraulic Cement:	
Portland Cement	AASHTO M 85
Blended Hydraulic Cement	AASHTO M 240
Pozzolans and Mineral Admixtures:	
Fly Ash	AASHTO M 295, Class C or F
Ground granulated blast furnace slag	AASHTO M 302, Grade 100 or 120
Silica Fume (microsilica)	AASHTO M 307
Water	AASHTO M 157
Aggregates:	
Coarse Aggregates	AASHTO M 80, Class A with amendments
Fine Aggregates	AASHTO M 6, Class B with amendments
Chemical Admixtures:	
Air-entraining	AASHTO M 154
Water-reducing and set-controlling	AASHTO M 194
Concrete Coloring	ASTM C979
Fibers	
Fibrillated polyolefin	ASTM D7508
Steel	ASTM A820

The basic material types used to proportion a concrete mixture are hereafter discussed on an individual basis in association with their materials standards. The benefits of using each of these material types as well as the potential constructability issues are also addressed.

2.2 Material Selection Driven by Exposure Conditions

The six basic concrete materials listed in Table 1 form the foundation for all concrete in highway infrastructure. However, selecting which cement type, admixture, or aggregate requires understanding the environment the concrete will face.

Concrete in a protected interior structure (parking garage) has minimal durability requirements. Concrete in a Minnesota bridge deck exposed to freeze-thaw cycling and deicing salt has severe durability requirements. Concrete in sulfate-bearing soil has chemical attack concerns that interior concrete does not face.

The durability requirements section that follows specifies exposure categories and the material limits associated with each. These are not guidelines or recommendations—they are minimum requirements. A structure specified for freeze-thaw exposure but installed with materials adequate only for dry conditions will deteriorate prematurely.

Understanding exposure category and translating it into material specifications is the engineer's fundamental responsibility in concrete design. The sections that follow detail how to make this determination for specialty concrete applications.

2.3 Exposure Category F (Freezing and thawing)

Freeze-thaw attack occurs in climates of repeated freezing and thawing. When temperatures drop below freezing, ice starts to form in concrete pores. Water increases in volume on freezing. Water confined in pores between freezing bodies is under compression and pores dilate causing the cement paste to rupture or crack. When concrete contains porous aggregate, the aggregate itself is prone to freeze-thaw damage even when the concrete contains air entrainment (see Figure 1).

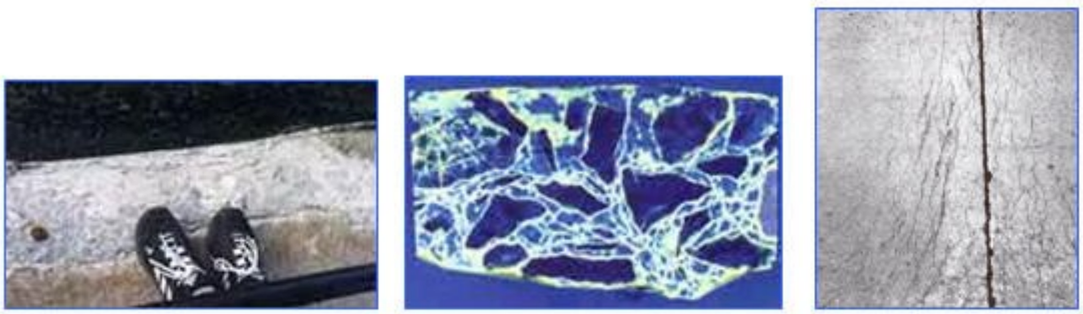

Figure 1: Concrete freeze-thaw damage (1) on the surface in the form of de-icer scaling; (2) throughout the thickness in the form of cracks in paste around aggregate; and (3) at pavement joints in the form of D-cracking.

Freeze-thaw deterioration is manifested on the exposed concrete surface by deicer scaling, crumbling and delamination. It is manifested throughout the thickness of the concrete by parallel surface cracks in paste and cracks in paste around aggregate. In pavements, freeze-thaw deterioration sometimes takes the form of D-cracking. D-cracking consists of closely spaced cracks that form parallel to pavement joints and progressively move outward. D-cracks are caused by porous aggregates. As water accumulates under pavements, the porous aggregates become saturated. When freezing and thawing cycles occur, cracking of the concrete typically starts in the saturated aggregate at the bottom of the slab and progresses upward to the wearing surface.

Freeze-thaw damage may be avoided by proper air entrainment of fresh concrete and use of nonporous aggregate. A good air void system provides free space to which water can diffuse and freeze without damaging the concrete. From a microscopic standpoint, air bubbles should be spaced no more than 230 µm apart and 10 to 1000 µm in size. Concrete air content requirements are based on the maximum aggregate size used.

In addition to specifying mixture proportioning requirements for maximum water-cementitious materials ratio and minimum specified compressive strength (f'c) for each freezing and thawing exposure class (F0, F1, F2 or F3), the FP and special contract requirements further mandate allowable air content ranges. To provide protection against freeze-thaw attack, the concrete mixture must be designed by the Contractor to meet air content requirements of the assigned freeze-thaw exposure class. It is noted that too much entrained air will result in detrimental strength loss. As a rule of thumb, the compressive strength loss is about 5 percent for each 1 percent of air content.

It is further noted that the FP limits the maximum total cementitious materials content pertaining to collective combinations of mineral admixtures (i.e. for concrete exposed to freezing and thawing and in continuous contact with moisture and exposed to deicing chemicals or the F3 exposure class). The requirements are are shown in Table 2.

Table 2: Maximum Cementitious Material Requirements.

Supplemental Cementitious Materials	Maximum Percent of Total Cementitious Material by Weight
Fly ash or other pozzolans, AASHTO M 295	25
Slag (GGBFS), AASHTO M 302	50
Silica Fume, AASHTO M 307	10
Total of fly ash or other pozzolans, slag, and silica fume	50(1)
Total fly ash or other pozzolans and silica fume	35(1)
(1) Limit fly ash or other pozzolans to no more than 25 percent of the total mass of cementitious material and limit silica fume to no more than 10 percent of the total mass of cementitious material.	

2.4 Exposure Category S (Sulfates)

Naturally occurring sodium, potassium, calcium or magnesium sulfates found in soil, dissolved in groundwater or from deicing chemicals can enter concrete and attack the cementing materials. Wetting and drying can replenish and concentrate salts on the concrete surface leading to continual attack. Sulfate attack disrupts the cement paste through one of two mechanisms: (1) formation of additional ettringite or (2) formation of additional gypsum. The formation of ettringite results in an increase in solid volume leading to expansion and cracking of paste. The formation of gypsum leads to paste softening and loss of strength. The presence of ettringite and gypsum in concrete, in and of itself, is not an indication of sulfate attack as these components are present in all concrete. In addition to chemical analysis, petrographic examination (ASTM C856) of hardened concrete samples is necessary to verify sulfate attack.

Figure 2: At the microstructure level, salt deposits (i.e. the formation of ettringite) are shown on a hardened concrete sample as well as cracking in the paste due to the formation and expansion of ettringite.

When in-service concrete will be exposed to soil or solutions (groundwater or deicing solutions) containing sulfates, a sulfate condition must be determined and the concrete mixture designed with the appropriate sulfate resisting cementitious materials types. Soil and/or water testing to determine the sulfate condition is accomplished as part of the project development with test results typically being included in Geotechnical reports. Measured test results are used by the Division Materials Engineer to assign an applicable sulfate exposure class which in turn is specified in special contract requirements on a project-by-project basis.

In addition to specifying mixture proportioning requirements for maximum water-cementitious materials ratio and minimum specified compressive strength (f'c) for each sulfate exposure class (S0, S1, S2 and S3), the FP and special contract requirements further mandate the use of sulfate resisting cementitious materials types. To provide protection against sulfate attack, the concrete mixture must be designed by the Contractor to meet the required cementitious materials type of the assigned sulfate exposure class. Alternatively, combinations of cementitious materials proposed for use in the mix design may be tested by mortar bar expansion in a sulfate solution. Mortar bar samples must be fabricated and tested in accordance with the procedure designated in the contract and meet the expansion limitation requirement of the assigned sulfate exposure class. The Contractor is further required to submit valid hydraulic cement materials certifications with the concrete mix design as part of form FHWA 1608. These certifications must include pertinent chemical and physical properties test data, including mortar bar expansion data when applicable, allowing verification of the use of appropriate sulfate resisting cement on the project (See Section 9.5).

2.5 Exposure Category C (Corrosion)

Concrete protects reinforcing steel because it provides a high pH environment around it. The pH of concrete, including that of the pore solution, is about 12.5. At a pH of 11.5 and higher, a passivating oxide film will form on the steel surface in contact with the concrete which protects the steel from corrosion. As long as the passivating oxide film forms and the high pH environment is maintained, the reinforcing steel will be protected from corrosion.

Reinforcement in concrete corrodes as a result of the failure to establish an initial passivating environment or by loss of an established passivating environment over time. The passivating environment may not initially form if the concrete exhibits excessive voids throughout its depth and at or near steel reinforcement if the concrete is porous. The passivating environment may be lost over time by concrete carbonation which lowers the pH pore solution near reinforcement steel to about 8.5. All concrete carbonates as a result of exposure to carbon dioxide in the atmosphere. The passivating environment may also be lost over time by ingress of the chloride ion into concrete which destroys the passive oxide film surrounding the steel.

As reinforcement corrodes, it increases substantially in volume resulting in delamination of overlying concrete and further structural deterioration. The effective load carrying area of the reinforcement is also reduced.

In addition to specifying mixture proportioning requirements for maximum water-cementitious materials ratio and minimum specified compressive strength (f'c) for each corrosion exposure class (C0, C1 and C2), the FP and special contract requirements further mandate limitations on the water soluble chloride ion (Cl^-) of the concrete mix ingredients when concrete is placed over reinforcing steel. To provide protection against reinforcement corrosion, the concrete mixture must be designed by the Contractor to meet the maximum water soluble chloride ion (Cl^-) content by weight of cement for the assigned corrosion exposure class and structural member type. The Contractor is further required to submit water soluble chloride ion (Cl^-) data on hardened concrete with the concrete mix design on form FHWA 1608. The data must verify that the maximum water soluble chloride ion (Cl^-) content of the mix ingredients has not been exceeded at the designated test age and that the concrete has been tested in accordance with the procedure designated in the contract.

Finally, for proper corrosion protection of the reinforcing steel, it is imperative that minimum concrete cover requirements stipulated by contract drawings be provided. Concrete cover over reinforcing steel should be checked in the field by the Project Engineer. Reinforcement steel cover can best be assessed in the forms prior to concrete placement.

2.6 Delayed Ettringite Formation (DEF)

Delayed Ettringite Formation (DEF), also known as internal sulfate attack, results in the formation of ettringite and associated expansion after heat curing at too high of a temperature. Many experiments have shown that pastes, mortars and concretes exposed to excessive temperatures during the hardening process exhibit expansion and cracking when subsequently exposed to moist conditions. The critical temperature for DEF is related to cement alkali content. Cements containing higher alkali contents (i.e. type III cements) exhibit lower critical temperatures. The FP limits elevated curing temperature to a maximum of 160 °F (71 °C).

The temperature of reinforced and prestressed concrete subjected to elevated temperature curing must be monitored by the Contractor and the maximum curing temperature recorded. It must be submitted with the concrete mix design (see FHWA form 1608).

2.7 Alkali-Silica Reactivity (ASR)

Alkali aggregate reactivity is the chemical reaction in either mortar or concrete between alkalis (sodium and potassium) from Portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of concrete or mortar may result. ASR is a type of alkali aggregate reactivity which involves reactions of the alkalis in Portland cement and certain siliceous rocks or minerals (i.e. opaline, chert, strained quartz, volcanic glass).

In order for ASR to be operative, three components are required including reactive silica, sufficient alkalis and sufficient moisture. Eliminating any one of these components will stop ASR reactivity and subsequent concrete damage.

Reactive silica refers to aggregates that tend to breakdown under exposure to highly alkaline pore solution in concrete and thereafter react with the alkalis to form an expansive ASR gel. Not all siliceous aggregates are reactive. Reactivity depends on aggregate mineralogy, crystalline structure and solubility of silica in the pore solution of concrete.

Sufficient alkalis refer to the alkalis predominately contributed by the sodium and potassium in Portland cement but also from other constituent materials and/or external sources. Such alkali sources include supplementary cementitious materials (fly ash, slag and silica fume), aggregates, chemical admixtures, deicing salts, seawater and wash water. The alkalis serve to raise the pH of the pore solution which in turn increases the solubility of the reactive silica.

Sufficient moisture refers to the moisture that is necessary to promote ASR expansion. If the internal relative humidity of the concrete exceeds 80 percent, sufficient moisture is present to allow ASR expansion. Such moisture is typically inherently present within concrete structures that are exposed to the environment or in contact with the ground (i.e. pavements, bridges, canals).

ASR occurs as the alkali and silica react to form a gel reaction product. The gel reaction product absorbs water and subsequently swells. When the volume of the reaction product is greater than the volume of the individual reacted materials, expansive tensile stress are exerted on the concrete and cracking occurs. The only indisputable evidence that ASR has developed in concrete is the detection of ASR reaction products. In the early stages of reactivity or under conditions where only small quantities are produced, ASR gel is virtually undetectable by the unaided eye. Final confirmation of the ASR mechanism must be performed at the microstructure level by a skilled petrographer.

A characteristic and advanced ASR cracking pattern is known as map or pattern cracking. The crack pattern resembles that which develops on dried mud flats. On concrete pavement surfaces, ASR cracks are typically more prominent in the wheel paths in the longitudinal direction. Below the pavement surface, ASR can be manifested by a predominance of vertical cracks in the upper 1 to 2 inches of pavement as well as cracks with sub-horizontal orientation. ASR cracks can extend completely through the pavement thickness.

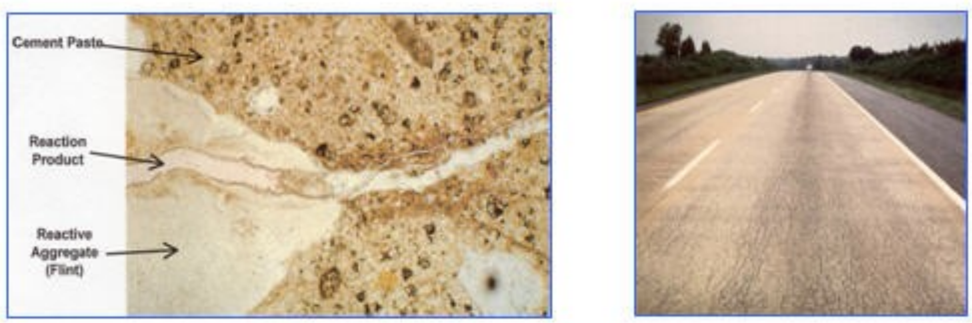

Figure 3: At the microstructure level, the characteristic ASR gel is shown within cracks that have formed through and around aggregate and into the surrounding paste. At the macrostructure level, an advanced and characteristic ASR cracking pattern known as map or pattern cracking is shown.

To prevent ASR in new concrete, the concrete mixture is designed to (1) control and limit the availability of alkalis in cement and/or (2) the type and amount of reactive aggregate.

Lowering of alkalis in the concrete mixture is accomplished by specifying the optional low alkalicement requirement found in Portland cement specifications in AASHTO M 85. The low alkali content serves to lower the pH of the concrete pore fluid which in turn decreases the solubility of the reactive silica. The optional low alkali-cement provision may be specified in the special contract requirements as a secondary, but not stand alone, means of ASR mitigation. If the low alkali option is allowed, the Contractor must submit valid hydraulic cement materials certifications with the concrete mix design which includes pertinent chemical and physical properties test data verifying the use of low-alkali cement on the project (See Section 9.5).

Limiting the type and amount of reactive aggregate in the concrete mixture is accomplished by one or more of the following:

- Testing aggregate sources to determine whether or not they contain reactive aggregates.
- Testing reactive sources to determine if the reactivity can be effectively mitigated by use of supplementary cementitious materials (i.e. fly ash, silica fume ground granulated blast furnace slag).

The FP and special contract requirements will specify reactive aggregate supplemental requirements for fine and coarse aggregates. Limiting the type and amount of reactive aggregate is the preferred and primary means of ASR mitigation.

The reactive aggregate supplemental requirements call for the use of non-reactive aggregates in the concrete mixture. Aggregate producers should be able to provide test results demonstrating the reactivity level of their product. The reactive aggregate supplemental requirements do allow for the use of reactive aggregates if supplementary mineral admixtures are added that demonstrably show prevention of harmful expansion by subsequent testing.

The Contractor is required to submit data from aggregate producers for both fine and coarse aggregate which documents aggregate reactivity levels as well as the test methodology used for measurement. If reactive aggregate is proposed for use, then test data must be included which shows that harmful expansion has been effectively mitigated by use of supplementary cementitious materials. However, the proportions of supplementary materials proposed for use in the concrete mix design must be similar to those showing effective mitigation by testing. The mix design proportions must also meet the maximum cementitious material requirements shown in Table 2. ASR testing as well as expansion criteria which is accepted by Federal Lands Highway is shown in Table 3.

Table 3: FLH Accepted ASR Testing.

Test Name	ASR Test Type and Application*	Sample Type and Size	Test Duration	Expansion Criteria
ASTM C1260	Immersion of mortar bars in NaOH solution at 80° C. (Evaluates aggregates only)	At least 3 mortar bars 1 x 1 x 10inches long 25 x 25 x 250 mm long)	16 days total – 14 days from zero measurement. Cannot be used to evaluate SCMs or Lithium	0.10% max at 16 days after casting
ASTM C1293	Concrete prisms stored at 38°C and 100% humidity. (Evaluates aggregate, SCMs and Lithium)	Three prisms per cement-aggregate combination not less than 3 x 3 x 10- inches long (75 x 75 x 250 mm long)	Measure after 1, 2, 4, 8, 13, 18, 26, 39 and 52 weeks. Every 6 months thereafter as necessary	0.04% max at one year
ASTM C1567	Immersion of mortar bars in alkaline solution at 80°C. (Evaluates SCMs)	At least 3 mortar bars 1 x 1 x 10inches long (25 x 25 x 250 mm long)	16 days total – 14 days from zero measurement. Cannot be used to evaluate Lithium	0.10% max at 16 days after casting
ASTM C295	Petrographic examination of aggregates	Varies; quarry samples of fine and coarse aggregate	Short term: visual and microscopic to assess reactive aggregate types	Used with ASTM C1260
ASTM C856	Petrographic examination of hardened concrete	One core specimen 6 inch diameter x 12 inches long (150 mm diameter x 300 mm long) or mortar bar sample	Short term: visual and microscopic to assess reactivity, cracks etc.	Used with ASTM C1260
* SCM stands for supplementary cementitious materials such as fly ash, silica fume or ground granulated blast furnace slag or a combination thereof.				

It is emphasized that ASR testing is included as part of the aggregate source quality testing shown in Tables 5 and 6. The Contractor should ensure that aggregate samples are submitted to the Government far in advance of the submittal of the concrete mix design in that some aggregate ASR tests take weeks to perform. As a minimum, ASTM C1260, which is used to ascertain whether or not aggregate is reactive, takes 16 days to perform after receipt and casting of test samples. Additional time will be necessary if supplementary petrographic analysis is required. Also, if reactive aggregate is employed in the concrete mix design, ASTM C1567, which is used to ascertain whether or not the use of supplementary cementitious materials has been effective in mitigating ASR expansion, takes another 16 days after receipt and casting of test samples. It is important to recognize and plan sufficient time for the Government verification testing for contract compliance with ASR requirements.

Chapter 3

Shotcrete Materials & Mix Design

3.1 Shotcrete Material Specifications

Shotcrete is composed of the same basic materials as structural concrete, namely hydraulic cement, mineral admixtures, water, aggregates, chemical admixtures and fibers. As such, the standard specifications for each of these materials, except aggregates, and the pertinent subsections of the FP which reference these material standards are applicable to shotcrete. For additional information, see Section 2.1.

The FP specifies that shotcrete fine and coarse aggregate must conform to AASHTO M 6, class B and AASHTO M 80, class A, respectively, including FP supplemental requirements. The fine and coarse aggregate source quality characteristics are similar to those for concrete, although the testing limitation requirements are different for shotcrete coarse aggregate.

Shotcrete aggregate must meet a combined grading requirement. The coarse aggregate amount is limited to less than 30 percent of the total mass. Shotcrete with more than 30 percent coarse aggregate has greater rebound, is more difficult to finish, cannot be used for thin layers and creates voids in the plastic shotcrete when shot at high velocity. The specific combined grading requirement is specified in the FP or by special contract requirements.

Acceptance of shotcrete materials is in the same fashion as acceptance of concrete materials. See Section 9.5 for an applicable discussion pertaining to materials certification acceptance as well as water and aggregate acceptance.

3.2 Shotcrete Mixture Proportioning and Preconstruction Requirements

The FP requires shotcrete mixtures to conform to specific ACI practices, specifications and guides including:

- ACI 506R Guide to Shotcrete
- ACI 506.2 Specification for Shotcrete

Shotcreting is a process which is highly dependent upon the specific equipment used, the unique placement skills of the nozzle operator and crew and conditions at the job site. Because of these factors, it is not standard practice to conduct laboratory trial mixtures. Instead, proposed shotcrete mix designs are submitted and preconstruction testing is performed in an environment that simulates actual job conditions to assess the quality of shotcrete produced by the crew and equipment that are proposed for use on the job. Shotcrete test panels are shot as a means to approve mix designs and pre-qualify crew and equipment.

3.2.1 Fresh Shotcrete Properties Sampling and Testing

Fresh shotcrete properties sampling and testing should be in accordance with ASTM C1385, which requires composite samples. A composite sample consists of several individual samples which are taken at various times during discharge and then combined into a single sample for testing. The final composite sample size must be large enough to perform the required tests. Sampling is performed as shotcrete material is delivered to the shotcrete machine.

For dry-mix shotcrete, the material is acquired by collecting two or more portions taken at regularly spaced intervals during discharge of the middle of the batch or at two or more random portions from the discharge of continuous mixers. The portions are combined into one sample for testing purposes. Portions should not be acquired from the first or last 15 percent of the discharge.

For wet-mix shotcrete, the sampling procedure is the same as the dry-mix process except the elapsed time between obtaining the first and last portions of the composite sample are as short as possible but no longer than 15 minutes.

Tests for air content by either AASHTO T 152 or AASHTO T 196 and unit mass per AASHTO T 121 must initiate within five minutes after obtaining the last portion of the composite sample.

3.2.2 Making and Curing Shotcrete Test Panels

Test panels are prepared and tested in accordance with ASTM C1140. Separate test panels are fabricated for:

- Each proposed test mixture representing each admixture type and dosage
- Each nozzle operator being qualified in association with each shooting position encountered at the jobsite (i.e. horizontal, vertical, overhead).

The test mixture must be of the same materials, admixtures and proportions proposed for use on the project as well as meet the required fresh and hardened concrete properties. Shotcrete must be applied using the same equipment, operating pressures and personnel as those proposed for the project.

Test panels must be constructed of wood or steel that is sufficiently rigid to prevent dislodging of shotcrete through vibration or deformation. To evaluate shotcrete mixture properties, mixture proportion test panels, containing no reinforcement are fabricated to a minimum width and length of 24 inches (600 mm) and a minimum depth of 6 inches (150 mm) with either square or sloped sides. When shotcrete is applied over reinforcement, additional test panels are constructed to evaluate reinforcement encasement and to determine the water-soluble chloride-ion concentration of the shotcrete mix ingredients. These panels must contain reinforcement of the same size and spacing as that required for the work. They must also be large enough to simulate jobsite conditions and are typically fabricated to a minimum width and length of 30 inches (760 mm) and a minimum depth of 3 inches (75 mm) with either square or sloped sides.

Panels containing no reinforcement are generally used to evaluate mix designs whereas panels containing reinforcement are used to prequalify personnel, equipment and application techniques. In instances where project shotcrete will not be applied over reinforcement, mixture proportioning panels containing no reinforcement are also used for prequalification purposes. Once nozzle operators and equipment have been approved, panels containing reinforcement are no longer constructed or evaluated on a project (i.e. they are needed for preconstruction testing purposes only).

Panels must be cured by tightly wrapping with a sheeting material meeting the requirements of ASTM C171 or stored in a moist room meeting the requirements of AASHTO M 201 as soon as is practicable after fabrication.

3.2.3 Hardened Shotcrete Properties Testing

Three-inch (75 mm) diameter cores are drilled from test panels to evaluate the compressive strength of the shotcrete mixture, the quality of the shotcrete coating produced by the nozzle operator and the water soluble chloride ion concentration of the mix ingredients. Cores are drilled, moisture conditioned and delivered to the designated laboratory for testing in accordance with contract specifications.

To evaluate compressive strength, at least three strength cores are drilled from mixture proportioning test panels, which contain no reinforcement, in accordance with AASHTO T 24. The 3-inch (75 mm) diameter cores must be acquired from the central 15 by 15 inch (380 by 380 mm) sample area and drilled perpendicular to the surface. Core ends should be sawed to ensure parallel, flat and smooth surfaces. Core specimens with length to diameter ratios equal to or less than 1.75 require corrections to the measured compressive strength. A 28-day compressive strength test result is calculated as the average strength of three individual core specimens taken from the same test panel. Additional cores can be obtained and used for information purposes such as obtaining 7-day strengths or other tests. They may also be used for mix design approval testing if specimens that have been previously tested show evidence of improper sampling, coring or testing and have to be discarded.

To evaluate the quality of the shotcrete coating that does not contain reinforcement, at least three samples are obtained in accordance with AASHTO T 24 from each mixture proportioning test panel that has been cured at least seven days. Samples may consist of cores or pieces of cores or test panels that are free from observable cracks, fissures or shattered edges. The samples are tested in accordance with ASTM C642 for density, boiling absorption and permeable void volume. No individual test may be greater than the maximum permissible boiling absorption and permeable void volume shown in the contract.

To evaluate the quality of the shotcrete coating for reinforcement encasement, at least three cores are obtained in accordance with AASHTO T 24 from nozzle operator and shooting position test panels that have been cured at least seven days. Cut surfaces are visually examined to check the uniformity of the shot material and to provide a basis for qualifying each nozzle operator in accordance with ACI 506.2. Cores are visually examined for voids, sand pockets, laminations, complete reinforcement encasement and other inadequacies. When initial prequalification test panel is rejected by the Project Engineer, a second test panel may be shot.

Additionally, the cores obtained for visual examination or others acquired from each test panel containing reinforcement are typically analyzed in accordance with ASTM C1218 at ages from 28 to 48 days to assess the water-soluble chloride ion concentration of the mix ingredients. No individual test may be greater than the maximum permissible water soluble chloride ion content shown in the contract. Water soluble chloride ion content analysis is performed during preconstruction testing only.

The discussion provided above is generalized to a typical shotcrete process. The FP as supplemented by special contract requirements provides the specific requirements for the preconstruction testing and the nozzle operator approval process for each project. The testing, evaluation and approval must be completed before proceeding to shotcrete construction.

3.3 Preconstruction Testing for Shotcrete

Shotcrete requires preconstruction test panel testing before production on the project. Test panels are cast using the proposed mix design, sprayed using project equipment and procedures, cured in conditions matching field conditions, and tested for strength and durability.

Test panels confirm that the nozzleman's technique, air pressure, water addition during spraying, and curing procedures will produce acceptable concrete. Without test panels, quality cannot be assured—shotcrete quality depends on operator skill and on-site procedures as much as on material proportioning.

Only after successful test panel results can the engineer authorize production shotcrete. This is a mandatory preconstruction step, not optional.

3.4 Shotcrete Mixture Approval Requirements

The FP requires shotcrete mix designs be submitted for approval. The submittal must be received at least 30 days before placing shotcrete.

The contractor must submit the required information to the Project Engineer who in turn will submit it to the Division Materials Engineer for approval. The Division Materials Engineer will review the submittal to ensure compliance with the contract requirements. Once the mix design and preconstruction testing has been approved, shotcrete construction may initiate.

Chapter 4

Shotcrete Construction & Inspection

4.1 Shotcrete Construction Requirements

The ACI practices, specifications and guides noted in the FP should be consulted regarding industry standards for producing shotcrete of acceptable quality throughout the construction process. The importance of proper sampling and testing cannot be over emphasized.

The FP requires that the as produced aggregate used in the shotcrete be sampled, tested and evaluated during construction. Combined aggregate gradation tests must be conducted to verify the uniformity of the supply. In addition, the Contractor should ensure that the water content of shotcrete mixture is adjusted in accordance with existing moisture conditions of the aggregate, which fluctuate in accordance with environmental conditions at the mixing plant site. Batch water content adjustments have been previously discussed in Section 1.2

The Project Engineer must ensure that the Contractor follows proper procedures for fresh shotcrete sampling and testing as well as witness the associated results for acceptance. The procedures used during construction are the same as for preconstruction. Shotcrete is typically tested and evaluated for air content, unit mass and compressive strength. The sampling and testing table included in the specifications provides guidance and direction on the sampling frequency and acceptance procedures. It is noted that wet mix shotcrete air content values are typically specified and applicable to composite samples that have been acquired from material delivered to the shotcrete machine prior to pumping. It is therefore expected that shotcrete will lose some entrained air during the pumping process and that the in-place air content will be less than the pre-pumped air content. The amount of air loss after pumping should be checked periodically. The final in-place air content should be at least 4 percent.

The compressive strength of the shotcrete is evaluated statistically during construction. A single compressive strength test result is the average result from three cores taken from the same test panel and tested at 28 days. The sampling and testing table included in the specifications will define the frequency for constructing panels to obtain cores for the compressive strength evaluation. The Project Engineer must ensure that the contractor follows proper procedures for making and curing test panels and obtaining compressive strength cores for hardened shotcrete properties acceptance testing.

The compressive strength and quality of the shotcrete coating must be closely monitored by the Project Engineer during the construction process. The shotcrete coating should also meet boiling absorption and permeable void volume requirements. If the compressive strength or quality of the shotcrete coating is unacceptable, corrective action must be taken before continuing shotcrete construction. If low strength test results occur, designers must perform calculations to assure that the load-carrying capacity of the structure is not impaired. If the likelihood of low-strength shotcrete is confirmed and there is a need for additional investigation, tests of cores drilled from the area in question may be performed. If it is necessary to obtain cores, the specimens will be obtained in accordance with AASHTO T 24. Contact the Division Materials Engineer for specific guidance regarding the sampling and testing of shotcrete that does not meet the contract compressive strength or coating quality requirements

4.2 Shotcrete Field Quality Control

Shotcrete placement requires continuous inspector oversight. Rebound (particles that bounce off the surface) represents waste and quality loss. Excessive rebound indicates improper techniques or material inconsistency.

Thickness verification using probe measurements confirms proper buildup. Curing procedures must prevent surface drying; shotcrete gains strength through hydration of cement, which requires moisture.

Field strength testing (cores extracted from the permanent structure) verifies that shotcrete quality meets specifications. These cores are typically tested after 7 and 28 days curing. Low results trigger investigation and potential rejection.

Chapter 5

Driven Piles

5.1 Driven Piles: Overview and Application

Driven piles transfer foundation loads to deep, competent soil or rock layers. Highway bridges, retaining walls, and other structures use driven piles when shallow foundations are inadequate.

Six pile types are specified in the Federal Lands Highway Field Materials Manual: steel H-piles, concrete-filled steel shell piles, concrete-filled pipe piles, precast concrete piles, sheet piles, and timber piles. Each type suits different soil conditions, load requirements, and environmental exposures.

Selection depends on subsurface conditions (boring logs), required capacity, installation equipment available, and environmental durability needs. A coastal bridge may require corrosion-resistant concrete piles; an inland structure might use steel H-piles.

Quality control for driven piles focuses on material certification and visual inspection during driving, rather than on field testing after installation.

5.2 Driven Piles

Materials requirements for driven piles depend on the pile type. Typical piles include:

- Steel H-piles
- Concrete-filled steel shell piles
- Concrete-filled pipe piles

- Precast concrete piles
- Prestressed concrete piles
- Sheet piles and
- Timber piles.

Driven piles are normally required to comply with AASHTO or ASTM materials requirements. Detail materials specifications are provided in Section 715 of the FP.

5.2.1 Steel H-piles

The FP requires that steel H-piles be fabricated from structural steel conforming to ASTM A572, ASTM A588, or ASTM A690, Grade 50 (345). The piles should be of the specified steel grade, length and section/weight. Steel H-piles sometimes require toe attachments (shoes) for hard driving conditions. Shoes fabricated from cast steel conforming to ASTM A27, Grade 65-35 (450240) or ASTM A148, Grade 90-60 (620-415) are recommended because of their strength and durability. H-piles are easily spliced either by full penetration groove welding along the web and both flanges or with manufactured splicers. Steel for manufactured splicers should also conform to ASTM A572, ASTM A588, or ASTM A690, Grade 50 (345).

5.2.2 Concrete-filled Steel Shell Piles

The FP requires that steel shell piles be either cylindrical or tapered pile shells of spiral welded, straight-seam welded, or seamless tube steel material. Steel shells can be driven with or without a mandrel, a heavy tubular steel section inserted into the pile to improve drivability. Mandrel driven steel shells are often fabricated from corrugated steel conforming to ASTM A36. Separate shell sections are usually screw-connected and waterproofed with an o-ring gasket. Steel shells that are driven without a mandrel are typically tapered or step-tapered and are required to be fabricated from no less than 3/16-inch plate stock conforming to ASTM A36. Separate shells driven without a mandrel may be either spirally welded or longitudinally welded. Concrete and reinforcement steel should comply with Sections 552 and 554.

5.2.3 Concrete-filled Pipe Piles

Pipe piles consist of seamless, welded or spiral welded steel pipes. The FP requires ASTM A252, grade 2 or 3 steel pipe piles. Pipe piles may be driven either open or closed end. Closed end pipe piles should be closed by welding a flat steel plate meeting ASTM A572, ASTM A588, or ASTM A690, Grade 50 (345). The pipe piles should be of the specified steel grade, length and minimum wall thickness. Typically pipe piles are spliced using full penetration groove welds. Manufacture splices, conforming to ASTM A572, ASTM A588, or ASTM A690, Grade 50 (345), should only be used if the splice can provide full strength in bending. Open ended piles may be reinforced with a steel cutting shoes meeting AASHTO M 103. Concrete should comply with Section 552.

5.2.4 Precast / Prestressed Concrete Piles

Precast and prestressed concrete piles are required to be manufactured to the applicable class of concrete specified in the contract. Additionally, they must have reinforcement consisting of a steel cage made up of several longitudinal bars or prestressing steel and lateral or tie steel in the form of individual hoops or a spiral. The piles should be of the specified length and section. Concrete piles should not be moved or transported until they have cured the minimum specified number of days or until concrete cylinders indicate that the concrete has reached the specified compressive strength requirements. Concrete piles delivered to the site should be free of cracks and spalling. They should be stored above ground with adequate blocking to prevent undue bending. Concrete piles can be difficult to splice and extend. The FP requires dowels or other acceptable mechanical means to splice precast and prestressed concrete piles. The contractor must submit drawings of proposed splices for acceptance. A short piece of structural H-section or “stinger” may be cast into or attached to the pile toe to assist in penetration. Concrete and reinforcement steel should comply with Sections 552, 553 and 554.

5.2.5 Sheet Piles

Sheet piles may be timber, reinforced concrete, vinyl, fiberglass, or plastic, but are most commonly steel. Steel sheet piles need to conform to AASHTO M 202 or ASTM A572. Timber and reinforced concrete sheet piles should conform to the same material requirements as timber and precast concrete piles. Vinyl, fiberglass and plastic sheet piles should conform to the manufacturers and special contract requirements. Joints between sheet pile sections should be made practically watertight when the piles are in place.

5.2.6 Timber Piles

Timber piles may be treated or untreated depending on the in-place conditions. Timber piles need to conform to AASHTO M 168 and treated, if required, according to AASHTO M 133, pressure method procedure AWPA Standard C1. Treated timber piles should be imprinted with the name of the treating company and type and year of the treatment according to AWPA Standards M1 and M6. The FP requires that timber piles be fabricated from Douglas fir, Larch, Red pine, Red oak or Southern pine. Steel straps are required to be placed on timber piles at not more than 10foot centers. The timber piles should be of the specified species, minimum length, and have the correct pile toe and butt sizes. The twist of spiral grain and the number and distribution of knots should be acceptable and the pile should be acceptably straight. Timber pile splices are difficult and generally undesirable. Cast steel shoes conforming to ASTM A27, Grade 65-35

(450-240) or ASTM A148, Grade 90-60 (620-415) should be used in hard driving situations.

5.2.7 Driven Piles Materials Acceptance

Driven pile materials acceptance, as stipulated in the FP, is based on visual inspection and certification. The contractor is required to furnish production certifications with each shipment of concrete piles, sheet piles, steel H-piles, steel shells, steel pipes and treated timber piles.

5.2.8 Driven Pile Materials Sampling and Testing

Concrete for steel shells and pipe piles are required to be sampled and tested according to Section 552.

5.3 Driven Pile Inspection and Acceptance

Driven piles are verified primarily through visual inspection and material certification. Mill test reports for steel and concrete must be on file before piles arrive.

During driving, the inspector observes for signs of damage: cracking, spalling, distress from driving stresses. Steel H-piles may experience bending or local buckling if driven at an angle or into obstructions. Concrete piles may crack if driving equipment is not properly cushioned or if soil resistance is unexpectedly high.

Pile straightness, condition, and installation depth are documented. Acceptance is based on compliance with these observations and on material certifications, not on subsequent laboratory testing.

Chapter 6

Drilled Shafts

6.1 Drilled Shafts: A Different Approach to Deep Foundations

Drilled shafts are large-diameter holes drilled into the ground and filled with reinforced concrete. Unlike driven piles (which are hammered into the ground), drilled shafts are excavated, then filled. This method suits sites where vibration or noise must be minimized, or where soil conditions make driving impractical.

Drilled shaft construction presents unique challenges: maintaining a stable borehole (often using mineral slurry), verifying concrete placement in the submerged borehole, and detecting voids or defects after concrete sets.

Mineral slurry, a bentonite and water suspension, holds the borehole walls stable during excavation. Concrete is tremied (placed through a pipe) at the bottom to displace slurry. Integrity testing (sonic or seismic methods) then detects anomalies (voids, soil inclusions, or structural defects) that could compromise capacity.

6.2 Drilled Shafts

Materials requirements for drilled shafts depend on the method of installation. There are three primary methods of installation. These include:

- Dry method
- Casing method
- Wet method

The dry method is applicable to soil and rock that are above the water table and that will not cave or slump when the hole is drilled to its full depth. The casing and wet methods are applicable to sites where soil conditions are such that caving or excessive soil or rock deformation can occur when a borehole is excavated. With the casing method, a steel pipe is placed at locations of instability. Slurry is sometimes used to temporarily stabilize the hole until the casing is inserted. The pipe is removed during placement of the concrete or remains permanently in-place. With the wet method, water or mineral slurry is used to keep the borehole stable for the entire depth of the excavation. The water or mineral slurry is displaced from the borehole when the concrete is placed. Detail materials specifications are provided in Section 717 and 725 of the FP.

As part of the construction phase of the drilled shaft work, a meeting should be held to discuss various aspects of drilling, constructing and logging of the drilled shaft. A sample drilled shaft meeting agenda is included in Appendix C of this course.

6.2.1 Casings

The FP requires that steel casing that are smooth, clean and watertight be used. The casings should be of sufficient strength to withstand handling and installation stresses and the concrete and surrounding earth pressures. The outside diameter should be no less than the specified size of the shaft. Steel casings need to conform to AASHTO M 270.

6.2.2 Mineral Slurry

Mineral slurry is a mixture of a clay mineral and potable water. Bentonite is most commonly used; however, attapulgite has been used in place of bentonite, usually in saline ground water conditions. Slurries made from synthetic polymers have been used as an alternative to mineral slurries, however, polymer slurries should be approved prior to use.

The bentonite and water need to be mixed outside the borehole and allowed to hydrate for several hours before using. The contractor should properly design and test the mineral slurry to ensure borehole stability. Because the properties of the mineral slurry change during excavation the FP requires that the contractor test and maintain density, viscosity and pH during excavation and until concrete placement. Chemical additives are sometimes used to control these properties. Because of economic and environmental concerns, slurries are typically circulated, conditioned and reused. To maintain the required properties the slurry usually needs to be decanted to remove sand. The FP limits the slurry sand content to less than 4 percent by volume.

6.2.3 Integrity Testing

Integrity testing is performed on drilled shafts using crosshole sonic logging according to ASTM D6760. The integrity testing is performed to identify any defective zones along the shaft, such as voids or borehole caving. The integrity testing is performed by lowering crosshole sonic logging probes down 2-inch diameter access tubes to measure and record pulse velocity according to ASTM C597. The access tubes, black steel pipe per ASTM A53, are installed with the reinforcement cage prior to placing the concrete. Integrity testing may not be required for relatively small diameter or short drilled shafts.

6.2.4 Concrete and Reinforcing Steel for Drilled Shafts

Concrete and reinforcement steel should comply with Sections 552 and 554.

6.2.5 Drilled Shaft Materials Acceptance

Drilled shaft materials acceptance, as stipulated in the FP, is based on visual inspection, certification and measured or tested conformance. The contractor is required to furnish a commercial certification and test results for the mineral slurry. Concrete and reinforcement steel are evaluated under Sections 552 and 554. The contractor is required to submit a detailed cross hole sonic logging report and test data in ASCII format for all production drilled shafts.

6.2.6 Drilled Shaft Materials Sampling and Testing

The contractor must sample and test the mineral slurry during excavation to ensure that the slurry properties stay within the acceptable ranges. Concrete for drilled shafts are required to be sampled and tested according to Section 552. Integrity testing is to be performed on all production drilled shafts according to ASTM D6760.

6.3 Drilled Shaft Materials and Verification

Concrete for drilled shafts must meet the same durability requirements as any highway concrete. In freeze-thaw climates, air entrainment and low water-cement ratios are mandatory. In sulfate-bearing soils, sulfate-resistant cement and material limits apply.

However, drilled shaft placement poses additional risks. Slurry contamination (bentonite, sand, or drill cuttings mixing with concrete) degrades strength and durability. Concrete must be placed carefully using tremie procedures to prevent segregation and contamination.

Integrity testing is mandatory for every drilled shaft. Sonic or seismic methods detect internal defects that sampling and testing alone cannot reveal. Low integrity test results prompt investigation: core drilling, additional testing, or structural analysis to determine if the shaft is acceptable.

Chapter 7

Protective Coatings & Painting

7.1 Protective Coatings: When and Why

Protective coatings (painting) are applied to steel and concrete structures to prevent corrosion and extend service life. Highway bridge girders, steel piles in marine environments, and concrete structures in aggressive exposures all benefit from coatings.

Coating selection depends on substrate (steel or concrete), exposure conditions (dry, wet, marine, industrial), and performance requirements (aesthetic vs. protective). Epoxy coatings resist water and chemicals. Urethane coatings provide UV resistance. Zinc-rich primers protect steel from corrosion.

Application success depends primarily on surface preparation. Inadequate cleaning, rust, or contaminants prevent coating adhesion and cause early failure. Professional application and thorough inspection are essential.

7.2 Painting

Protective coating systems are widely used on bridge and highway structures primarily for corrosion control of metals and to protect timber and concrete from deterioration. The coating system protects by isolating the environment from the substrate, by barrier, sacrificial means or a combination. There are many ingredients that constitute a coating material, but they can generally be categorized as non-volatiles and volatiles. The non-volatile component is that which remains on the surface after the volatile component evaporates. Non-volatiles include resins, pigments and additives. The resin or binder is the filmforming component of the coating. It promotes adhesion to the substrate or previous coating layers. Resin systems include acrylic, alkyd, oil, vinyl, epoxy, and urethane. The pigment gives the coating system its color and determines gloss level, but can also be used for corrosion resistance, act as a barrier and to increase the solids content. Additives are used to adjust certain properties of the coating. The volatile component is a solvent or solvent blend. The solvents are used to dissolve the resin in the coating and reduce the viscosity so that it can be applied. The non-volatiles are stated as a percentage of the total volume, known as the "Solids by Volume". The percentage of solids by volume is used to calculate wet film thickness and coverage rates of the coating.

7.2.1 Coating System Components

A coating system includes the surface preparation and the application of a specified number of coats. The coats include a primer, intermediate and top. Each coat requires the application of multiple passes to achieve the specified thickness. Contrasting colors are often used to assist the contractor in assuring coverage. Each coating layer has a specific purpose. The primer provides adhesion to the substrate and can act as a barrier, rust inhibitor or sacrificial layer. The intermediate coat provides additional barrier protection, thickness and forms a tie between the primer and top coat. The top coat is used for aesthetics and corrosion protection. For a successful coating system it is critical to ensure that the specified surface preparation has been achieved and that each coat is applied to the specified thickness.

7.2.2 Coating Types

The following generic coating types are specified in the FP:

- Alkyd
- Epoxy
- Urethane
- Moisture cured urethane
- Zinc-rich, and
- Acrylic latex.

7.2.1 Alkyd

Alkyd coatings are relatively inexpensive, flexible, easy to apply and can be modified with other resin systems for enhanced characteristics. An alkyd modified with silicone will provide good ultraviolet resistance and gloss retention. Alkyds cure by oxidation and can be very slow drying. They can also tend to chalk and fade (without silicone modification), have fair to poor acid and alkali resistance and poor solvent resistance.

7.2.2 Epoxy

Epoxy coatings exhibit excellent adhesion, acid, alkali and solvent resistance and good flexibility. They offer abrasion, corrosion and chemical resistance. Epoxy coatings cure by cross-link polymerization. If too much time passes before top coating, they may harden to the point where subsequent coats will not adhere. Epoxy coatings are two-component and must be mixed properly to achieve full cure. They have a limited pot life and have poor resistance to sunlight.

7.2.3 Urethane

Urethanes are commonly specified as top coats because they have superior gloss and color retention. They also have good adhesion, as well as good acid, alkali, impact and abrasion resistance. Urethane coatings are typically higher priced than other coatings. They are sensitive to moisture during curing and may develop a haze or blush that must be removed prior to top coating and they can cause pinholing in the top coat. Urethanes cure by cross-link polymerization and require careful mixing to achieve full cure. They also have a limited pot life.

7.2.4 Moisture-cured Urethane

Moisture-cured urethane coatings cure by a reaction with moisture in the air. They are single component, surface tolerant, easy to apply and some can cure at low temperatures. They also have excellent chemical and solvent resistance and gloss retention. During packaging, a "nitrogen blanket" is floated along the top of the coating prior to sealing the lid. Once opened, the nitrogen dissipates, exposing the content to moist air. The coating may subsequently harden in the container, even if the lid is re-secured. The minimum relative humidity should be 40 percent during application and curing of moisture-cured urethane coatings.

7.2.5 Zinc-rich

Zinc-rich coatings are primarily used as primers to provide galvanic protection. There are two categories of zinc-rich coatings: inorganic and organic. The difference is with the binder. Inorganic zinc-rich coatings contain an inorganic binder such as ethyl silicate, while organic zinc-rich coatings contain an organic binder such as, alkyd, vinyl, epoxy and urethane. The inorganic zinc rich coatings may provide better corrosion protect but are not as easy to apply as the organic zinc-rich coatings. The inorganic zinc-rich coatings are less tolerant of deficient surface preparation and can mud crack at excessive thickness and are more difficult to topcoat. They are also very porous and can cause pinholes in the top coat.

7.2.6 Acrylic Latex

Acrylic latex coatings are relatively easy to apply and clean up. They cure by solvent evaporation and coalescence. Because the solvent system is primarily water, these coatings comply with VOC regulations. Acrylic latex coatings have poor resistance to alkali and solvent, and have moderate abrasion resistance. They must be applied in temperatures above 50 °F.

*7.2.7 **Vinyl***

Vinyl top coats were regularly used by highway agencies in the past. However, vinyl coatings are typically 65-70% solvent. Therefore, vinyl coatings are typically not VOC compliant and are no longer used on highway structures.

7.2.3 Curing

There are four basic coating curing mechanisms:

- Solvent evaporation
- Polymerization
- Oxidation
- Moisture cure

Coatings that cure by solvent evaporation contain a resin and pigment in a solvent blend. The solvent evaporates leaving the resin and pigment behind. Because there is no chemical reaction the resin can be redissolved. Therefore, coating that cure by solvent evaporation cannot be over coated with a coating containing strong solvents, as it will dissolve the underlying layer. Acrylic latex coatings cure by solvent evaporation. Coatings that cure by polymerization are multicomponent. The components, once mixed together, react chemically to form a solid, rigid, resistant coating film. Coatings that cure by polymerization include two part epoxies, urethanes and two part organic zincs. Similar to polymerization, oxidation is the reaction of two components to form a single coating layer. However, the coatings are one component and oxygen in the atmosphere is the catalyst. Alkyds cure by oxidation. Moisture cure coatings react to moisture to cure. Moisture cure coatings include inorganic zinc-rich primer and moisture-cure urethane.

7.2.4 Surface Preparation

Surface preparation is the key element in determining the ultimate success or failure of a protective coating system. Prior to surface preparation, structural steel and concrete surfaces may require some amount of repair. For steel surfaces, welding, cutting, grinding or filling of crevices may be required. For concrete surfaces, patching and filling cracks and pores with surfacing compounds may be required. The purpose of surface preparation is to impart a specified level of cleanliness and roughness into the surface. This can in some cases be achieved in one step, however, cleanliness and roughness are two different specification criteria and must be examined independent of one another. There are eleven cleanliness standards provided in the Society for Protective Coatings (SSPC) specifications. The standards typically used for cleaning steel structures include solvent cleaning, hand tool cleaning, power tool cleaning, commercial blast cleaning, and near-white blast cleaning. Contact the Division Materials Engineer for SSPC specifications and visual reference guides for surface preparation.

7.2.5 Application

It is important to review and be familiar with the Manufacturer's product data sheets. They have important information that is critical to a successful application. They should also be reviewed to make sure that they comply with the specifications. There are three primary methods of transferring the coating material from the can to the surface. These include brush, roller and spray. The contractor will choose the method of application based on the coating type and location of application. Regardless of the application method selected the coating must be applied to provide uniform coverage to the specified thickness.

7.2.6 Inspection

The painting contractor is required to be certified according to SSPC-QP1, "Painting of Complex Industrial Structures" and SSPC-QP2, "Removal of Toxic Coatings form Complex Industrial Structures". The approved contractor's quality control plan should identify the personnel responsible for painting inspections and should include a detail list of quality control test to be performed. Inspections should include verifying the removal of weld spatter, grinding of sharp edges and removal of grease, oil, dirt and debris, prior to surface preparation. Measurements should be made and recorded for the weather conditions, including air and wet bulb temperature, relative humidity, dew point temperature, surface temperature and wind velocity. Readings should be taken about every four hours, more often if conditions appear to be changing. Weather conditions should be within the limits of specifications and the coating manufacturer's data sheets. Cleanliness and surface profile should also be verified prior to applying the coating. If compressed air is used, the cleanliness of the compressed air should be verified. Inspections of the coating materials should be performed to verify that the components are mixed properly, proper thinning procedures are being followed and that materials are discarded once the pot life has expired. At the start of the application, the inspector should verify that good coating application techniques are being used. After the coating is applied the wet and dry film thicknesses need to be measured. Finally, adhesion and gloss retention may also be checked.

It is a good idea to have a pre-painting meeting to identify the role and responsibilities of those involved, and to discuss safety measures, contractual details and inspection and measuring requirements.

7.2.7 Safety

The contractor is required to submit a plan for approval that details the measures to be used for protecting the environment, public, adjacent property and workers. The primary source of information for coatings, thinners and abrasive blasting material is the Material Safety Data Sheets (MSDS). The contractor is responsible for ensuring that MSDSs are available for each chemical used on the jobsite and are readily accessible to employees when they are in the work area. Employees should follow the precautions for safe handling and use personal protective and mechanical equipment if required. In addition all containers must be labeled, marked and tagged. The contractor safety plan should also include information about fall protection/fall prevention. Approved fall protection/fall prevention systems should be used during painting operations.

Toxic metals, including lead and chromium, may be found in paints or coatings already in place on bridges. The contractor must follow all OSHA health standards to protect employees working with toxic metals. The contractor must also follow all applicable federal, state and local environmental regulations for the protection of air, soils and water. Waste must be properly stored and disposed. The generator is always the owner, but the contractor can be named as a cogenerator. The generator will provide an EPA identification number, which is obtained from the state or local EPA office. Waste cannot be transported or disposed of without an EPA identification number. Samples of the waste stream must be randomly selected and analyzed to determine the toxicity. When working with hazardous waste, the contractor must monitor the ambient air levels and conduct pre- and post-job sampling and testing of soil and water/sediment, to ensure compliance with regulations.

7.2.8 Painting Materials Acceptance

Painting materials acceptance, as stipulated in the FP, is based on visual inspection and certification. Should there be a need to sample the paint for verification of the certification provided, contact the Division Materials Engineer for guidance in the proper sample size and method to obtain material for testing.

7.3 Coating Application and Inspection

Surface preparation, cleaning, abrasive blasting, and removal of contaminants, is 80% of coating success. A pristine surface ensures adhesion; poor preparation guarantees failure regardless of coating quality.

Dry film thickness (DFT) measurement verifies that adequate coating has been applied. Holiday detection identifies pinholes or bare spots where coating did not adhere.

Weather constraints are critical; temperature and humidity limits prevent adhesion and proper curing. Application in rain, fog, or temperature extremes produces poor results.

Inspector oversight during application ensures compliance with procedures. Safety precautions (ventilation, personal protective equipment, emergency response) protect workers during application and curing.

Chapter 8

Sampling, Verification & Field Acceptance

8.1 Sampling and Testing for Specialty Concrete Applications

Sampling for specialty concrete applications follows the same general procedures as standard concrete: representative samples, split samples, chain of custody. However, specific applications have unique requirements.

Shotcrete test panels are cast and sprayed during preconstruction, then cored for testing. Drilled shaft concrete is tremied into place; samples are obtained from the concrete truck before placement, not from the borehole. Driven pile materials are certified; little field sampling occurs after installation.

All sampling requires witness by the Project Engineer. Split samples are obtained and tracked. Test procedures follow ASTM standards applicable to the specific application.

Professional judgment guides the intensity of field testing and verification. High-risk applications or new contractors warrant more intensive testing.

8.2 Sampling

The control of material is an important part of any construction project. It can only be accomplished when the material being incorporated into the work is acceptably inspected, properly sampled, and accurately tested. The importance of obtaining a good representative sample cannot be overstated.

Samples obtained or used on construction projects have different purposes. Samples can be obtained to verify proper testing is being performed, to control production processes, or to verify product quality. Here are the general sample types and purposes that are typically used on FLH construction projects:

- **Quality Control (also called process control) Samples.** These samples are obtained by the contractor for the purpose of assessing and making adjustments to a production or construction process. Samples, taken during production, assist the contractor in making appropriate corrections for producing a quality product. Information obtained by testing these samples is used by the contractor to control the level of quality of the furnished end product. The contractor may take a quality control sample at any time. However, when the quality control sample test results are to be utilized in the material acceptance decision, the Government will randomly identify the material to be sampled and tested.

  The Government will witness the sampling and splitting procedures and will immediately take possession of the Government's split portion of the sample. The Government must maintain control and custody of the sample at all times to ensure the integrity of the testing and verification process.

- **Acceptance Samples.** These samples are tested by the government to determine conformance to contract requirements.
- **Verification Samples.** These samples are obtained by the contractor; witnessed and tested by the government or its designated laboratory for the purpose of verifying the results of contractor tested quality control samples. The results are used in a statistical evaluation for the purpose of acceptance and payment. In the event that the contractor's test results are not verified, the Government's test results will be used for acceptance and payment for the material.
- **Independent Assurance Samples**. Any qualified person from a qualified laboratory, as defined in the contract, which are not associated with the contractor or the FLH project inspection staff, can take an Independent Assurance (IA) sample. This sample can be taken at any location and at any time within the project. The purpose of this sample is to provide an unbiased and independent evaluation of the sampling and testing procedures used in the acceptance decision. IA samples evaluate the sampling and testing personnel and their associated equipment. The sample cannot be used in the acceptance decision for the material since it is a biased non-random sample used to evaluate testing personnel and equipment. The Division Materials Engineer evaluates the results to determine if any discrepancies exist in the sampling and testing.
- **Proficiency Samples.** These samples are manufactured by the FLH central laboratory and used as a tool to evaluate the quality of the testing being performed for a project. The results are used in the same manner as the independent assurance samples. The Division Materials Engineer evaluates the results to determine if any discrepancies exist in the testing.

In all cases, it is critical to obtain a representative portion of the manufactured product that will be tested to verify that the material used or the work done conforms to the requirements of the contract. The use of proper sampling procedures and techniques is a vital piece of the verification process for quality highway construction.

8.2.1 Sampling Responsibilities

Generally speaking, the contractor is responsible for obtaining all of the samples on a construction project. The sampling process takes place under the supervision or witness of the Project Engineer or government representative. In addition to acquiring the sample, the contractor is also responsible for splitting the sample, if appropriate, and providing a split portion of the sample to the government. When results of the contractor testing are to be considered in the acceptance decision, the contractor needs to ensure that a government representative is present during the sampling and splitting process. Once this has been accomplished, the government will take immediate control of the sample. This sample may then be tested and the results used as part of the verification process. It is vitally important for the integrity of the acceptance process that the sampling is witnessed and that the chain of custody for the government portion of the sample has not been compromised.

The contractor is responsible for following proper sampling and testing methods in accordance with the submitted quality control plan and the contract specifications. This includes monitoring, certifying, or verifying the quality of products manufactured off-site and delivered to the project meet contract specifications. At a minimum, the contractor is required to perform all sampling and testing listed in the sampling and testing tables provided in the contract.

The Project Engineer is responsible for verifying that the required sampling is accomplished according to standard procedures and that the material used and work performed on the project, whether produced on the project or manufactured off-site and delivered to the project from an outside source, comply with contract specifications. In addition, the Project Engineer will ensure that all samples used to evaluate work for acceptance are retained until final acceptance.

8.2.2 Sampling Procedures

Established sampling methods provide specific guidance regarding the amount of material required for the sample. This amount should not be confused with the amount of material needed to perform the proper testing. The sample obtained needs to be taken in accordance with the appropriate referenced method. Subsequent testing is usually performed on a smaller representative portion of that sample. These smaller testing amounts will be specifically stated in the appropriate test method for the given material.

Project personnel should be knowledgeable in the following sampling criteria that are required by the contract.

- **Minimum required sample size.** The sampling methods, typically cited as AASHTO or ASTM methods, identify the size sample required for the particular material.
- **Sampling frequency.** Sufficient samples must be taken to represent the material that is delivered to the project for assurance that it complies with specification requirements. A non-uniform product can require more samples than the minimum specified in the contract for acceptance of its quality. For acceptance purposes, the contract will specify the minimum sampling frequency.
- **Sampling methods.** Different materials require different sampling methods. The appropriate test methods should be used to ensure a proper

sample has been obtained. These methods will be referenced in the contract documents and also in this manual.

- **Sample location.** Where practicable, samples to be tested for acceptance shall be obtained from the finished product. The contract specifications identify where samples are to be taken for acceptance and at what minimum frequency.

8.2.3 Sampling Methodologies

Samples may be obtained at any time and at any location. Specific contract language in subsection 106.01 states that the government may inspect, sample, or test all work at any time before final acceptance of the project. In general, there are two sampling methodologies.

- **Selective sampling.** This is a biased non-random procedure in which a sample of material is obtained from a specific location determined by observation. The information obtained from the testing of this sample can be used to determine compliance with the contract but cannot be included in any statistical evaluation. This methodology may be used at any time.
- **Random sampling.** This is an unbiased sampling procedure in which a sample of material is chosen in such a manner that any incremental amount of material placed has an equal probability of being selected. For the statistical concepts and comparisons to function properly, the sample used for statistical acceptance must be selected on a random basis. Random sampling locations are selected in advance of the production and placement of the material to be sampled. These locations should be selected using random numbers generated by use of random number tables, the random number function on a calculator, or the random number function in computer software. QL-PAY has a random number generator developed specifically for use with highway construction materials.

8.2.4 Sample Handling

Samples need to be stored and handled appropriately to ensure that the integrity of the material has not been compromised. The samples need to be properly labeled and identified so that all information regarding the sample location and test results can be correlated. If the samples are to be transported, use proper containers to maintain the integrity of the sample throughout the shipping process. Include a Request for Laboratory Tests form, FHWA 1600, for all samples shipped to the central laboratory.

8.2.4.1 Sample storage and retention

Once the government takes possession of the sample, it should be handled and stored in an appropriate manner. Care should be taken to avoid damage to the sample container, disturbance of the sample, or contamination. The Project

Engineer will store, handle, label and date samples in a manner that will preserve the character of the material. Most samples should be stored in a dry environment and kept free from contamination until final acceptance of the project. It is important that all samples be cared for in this manner in the event that complete testing of verification or acceptance samples becomes necessary.

8.2.4.2 Sample labeling

When obtaining the sample, the contractor will need to label the sample container with the appropriate project information. As a minimum, the following information should be included on any sample. Additional information may be required depending on the specific location and/or purpose for the sample.

- Project name
- Project number
- Pay item number
- Pay item description
- Sample number
- Lot number
- Sublot number
- Date
- Location of sample

8.2.4.3 Sample transport and shipment

Ship samples in a container of sufficient strength to prevent the loss, contamination or damage of the contents during shipment. Sufficiently identify all samples to facilitate reporting, logging, and tracking of sample information. Table 1 provides a brief summary list of containers to be used for common highway materials. If additional guidance is needed for a particular material, contact the Division Materials Engineer.

Table 4: Common Sample Containers.

Material	**Appropriate Sample Container**
Soil and Aggregate	Clean tight woven canvas sacks 5-gallon plastic buckets with tight lids
Cement, Lime, Fly ash	1-gallon watertight containers
Asphalt binder and cutback asphalts	1-quart cans
Emulsified asphalt	1-gallon large mouth plastic jugs with screw top lids

Asphalt mixture – uncompacted	6" x 12" cylinders 5-gallon plastic or metal buckets Cardboard box of sufficient size
Asphalt mixture – cores	Cushioned container 4" x 8" or 6" x 12" plastic concrete cylinder molds with appropriate packing
Concrete cylinders	Appropriate sized concrete cylinder molds shipped in a sturdy box with insulation and padding

8.2.5 Request for laboratory testing

All samples shipped to the FLH division laboratory must have a Request for Laboratory Tests form, form FHWA 1600, to provide instruction as to the testing to be performed. The form should be completed by the Project Engineer and attached to the outside of the sample container in a manner that will protect it during shipment. A duplicate copy should be placed inside the shipping container. The form can also be faxed or electronically sent in advance of shipment to alert the lab personnel that a sample will be arriving.

8.3 Verification Processes

8.2.1 Verification of Material Quality

Regardless of which acceptance method is used, it is always necessary to verify the quality of materials incorporated into the work. The responsibility for final acceptance of all materials rests with the Contracting Officer. Therefore, the Project Engineer must be confident that the results obtained on which the acceptance decision is based are valid. Using qualified laboratories and qualified technicians facilitates achieving a quality project and having reliable test results on which to base acceptance decisions.

Whenever there are at least three samples tested by both the contractor and the Government, comparison of the results should be performed by entering them into QL-PAY. QL-PAY uses statistical procedures to analyze the data and determine if there are significant differences between the contractor's and Government's results or if the results are within what would be considered normal limits of variability. If the results are within normal variability limits, the contractor's results would be considered valid. If the results are not within normal variability limits, QL-PAY will issue an alert. It is essential that the Division Materials Engineer be contacted immediately and review the data before any action is taken. A final determination as to the validity of the contractor's results must be made by an individual having a background in both statistical analysis and materials in order to avoid making an incorrect decision.

When there are fewer than three samples tested by either party, the comparison cannot be done in QL-PAY. In those instances, the results of samples should be compared using the multi-laboratory precision limit specified in the applicable test method. This provides an acceptable range for two results obtained from different laboratories by different operators. If the results are within the multi-laboratory precision limit, the contractor's results would be considered valid.

8.3.2 Visual Inspection and Certification

Acceptance verification of material quality may be by visually inspecting the material and verifying the certification. If the Project Engineer has any doubts regarding material quality, he has the right to obtain a sample and have it tested and should do so. Normally, if a sample is desired, it should be obtained by the contractor in the presence of the Project Engineer with the Project Engineer determining the location of the sample. The Project Engineer should take immediate possession of the sample after it is obtained (and split if desired). The sample is usually obtained by using random numbers; however, the Project Engineer may elect to test in a specific location to verify the quality of the material.

8.3.3 Measured or Tested for Conformance

The Project Engineer should normally obtain and test a minimum of three random samples; however, for small quantities fewer samples may be appropriate. In the case where the Project Engineer has suspicions concerning the quality of the material, the Project Engineer may direct the contractor to obtain one or more samples from the suspect area rather than use random samples. The Project Engineer should take immediate possession of the sample after it is obtained (and split if desired) by the contractor.

8.3.4 Statistical Evaluation of Work and Determination of Pay Factor (Value of Work)

For this type of material acceptance, the contract specifies the sampling frequency and the Project Engineer determines the random location of all the samples. All samples intended for use in the acceptance decision must be obtained by the contractor in the presence of the Project Engineer. The sample location should not be revealed to the contractor until moments before the sample is to be obtained. The Project Engineer should take immediate possession of the sample after it is obtained and split. All comparisons of results should be made in QL-PAY.

8.4 Acceptance of Work and Value Determination

Acceptable work conforming to the contract should be paid for at the contract unit bid price. When material or work fails to meet the established specification, the material or work shall be removed and replaced unless in the public interest the Government consents to accept the work with an appropriate adjustment in price or corrective action. If the contractor requests to have the work accepted at a reduced price or requests permission to perform corrective measures, the request will be evaluated based on the public interest. It is the contractor's responsibility to submit a proposal outlining any action that will be taken in lieu of removal and replacement. The contractor may submit a written request to:

1. Have the work accepted at a reduced price; or
2. Be given permission to perform corrective measures to bring the work into conformity.

A written request must contain supporting rationale and documentation. This would include references or data justifying the proposal based on an evaluation of test results, effect on service life, value of material or work, quality, aesthetics, and other tangible engineering basis.

If the contractor submits a written request, the following process outline provides guidance for addressing the request to accept work at a reduced price:

- Meet to discuss the non-compliance material or workmanship. The meeting should include the Project Engineer, Construction Operations Engineer, and Technical Services Branch representative with expertise in or responsibility for the area of concern (i.e., bridge, hydraulics, materials).
- Review test data to determine the significance of non-compliance.
- Evaluate the degree of deviation from contract requirements. Such evaluation is a subjective process and must take into account the criticality of the material or work, the risk associated with any deviation from the contract requirements, and the degree of deviation from contract requirements.
- Reduce the contract unit price for the item in question depending on the significance of the noncompliance. The percent reduction in the unit price are based on the following guidelines:

  0 to 5% Material substantially meets the contract requirements with minor deviations from the specifications.

  6 to 15% Material fails to meet contract requirements and results in the use of an inferior product. Generally, this material will result in a reduction in the usable life of the item in question.

  16 to 75% Material fails to meet contract requirements by a significant amount and is clearly and inferior product. Use of this material may meet the intended purpose; however, the quality is well below that specified. The criticality of this material may be low and does not warrant removal or other corrective action.

Likewise, corrective actions need to be evaluated to determine the level of effectiveness. The remedial/corrective work must provide results that are more desirable than reducing item pay amounts. In certain instances, corrective actions may be used in combination with a contract bid price reduction.

When it is determined that the material or work does not meet the intended purpose or results in substantial quality or safety deficiencies, it shall be removed and replaced.

Chapter 9

Roles, Responsibilities & Documentation

To ensure a successfully completed construction project, specification compliant materials need to be incorporated into the work. The contractor quality control plan provides, among other items, the system to measure and validate the quality of the materials used. Major components of the plan are 1) personnel, 2) equipment and testing laboratories, and 3) sampling (see above). The contract provides specific requirements for the contractor quality control system. The purpose of this chapter of the course is to provide general guidance regarding elements that may be included as part of the construction project quality control activities.

9.1 Personnel

Individuals performing sampling and testing of materials to be used in the construction of FLH projects must be knowledgeable in the sampling and testing procedures and requirements of the contract. In addition to sampling and testing requirements testing personnel must also be familiar with proper use and calibration of equipment required for the testing of materials.

In general, contractor personnel assigned to perform sampling, testing, or inspection functions should have 1 year or more of recent job experience in the type of sampling, testing or inspection required by the contract. Qualifications can also be demonstrated through other certifications or participation in proficiency testing. Examples of these types of qualifications include:

- NICET Level II certification in highway materials, or State Highway Agency (SHA) or industry certification-related sampling and testing equivalent to their contract responsibilities.

- Nationally accepted certification for intended sampling and testing responsibilities, i.e. WAQTC, ACI, NETTCP.
- Current or previous employment by an AASHTO accredited laboratory performing sampling and testing equivalent to their intended responsibilities.
- Demonstrated proficiency or successful testing of one or more proficiency samples (may be substituted for basic qualifications pending verification of test results).

9.1.1 Qualification Documentation

Before the start of the work, the Project Engineer should obtain documentation supporting personnel qualifications. Documentation requirements are listed in the contract.

9.2.1 Subcontracted Sampling and Testing

If sampling, testing or inspection is to be performed by a subcontractor, the Project Engineer should request from the prime contractor detailed information about how the sampling, testing and inspection by the subcontractor will interface with the prime contractor's work and other subcontractors performing work required by the contract.

The contractor is required to have a quality control system that includes the appropriate process control of material. The Project Engineer is responsible to ensure that material being incorporated into the work conforms to the contract requirements as supported by the appropriate inspections, sampling, and testing.

9.2 Equipment and Testing Laboratories

Testing of materials used in highway construction projects requires specialized materials testing equipment. Laboratories are essential to assure quality materials are incorporated in the project. Laboratories must be adequately staffed and properly equipped to conduct materials tests required by the contract quality control provisions.

The Project Engineer is responsible for inspecting, verifying, and documenting that field laboratories are properly equipped and staffed prior to the start of the work that requires sampling and testing.

9.2.1 Contractor-furnished Laboratories

The contractor may use a commercial laboratory or an on-site contractor furnished laboratory. The commercial or on-site contractor furnished laboratory must be equipped with all the testing equipment and accessories to meet contract sampling and testing requirements.

Laboratory facilities should be kept clean and equipment maintained in proper working condition. Subject to the terms of the contract, the Project Engineer has unrestricted access to the laboratory for inspection and review.

9.2.2 Government-furnished Laboratories

A government-furnished field laboratory trailer may be available for rent. If this is the case, the government will offer to the contractor a furnished field laboratory with testing equipment. Field laboratory availability and a listing of the testing equipment included in each field laboratory may be obtained by contacting the CO. Due to the wide-range of construction complexity for FLH projects, the laboratory facility may not be equipped with all of the necessary testing equipment required for the project. It is the responsibility of the contractor to review the basic equipment list and provide any specialty or missing testing equipment needed for use on the project.

In general, the laboratory includes testing equipment to conduct process control and project acceptance testing for embankments, crushed aggregate base, asphalt paving materials, and plastic concrete. Other equipment, such as equipment for breaking and curing concrete cylinders, may be included on a specific contract basis. The Sampling and Testing tables located at the end of each Section in the contract will provide references to test methods and procedures that include the equipment requirements.

The laboratory facility should be kept clean and equipment maintained in proper working condition. Subject to the terms of the contract, the Project Engineer has unrestricted access to the laboratory for inspection and review.

9.2.2.1 Laboratory Cost

Field laboratory trailer and testing equipment are offered to the contractor at a cost specified in the contract. The contractor shall replace at their cost or be responsible for the replacement cost of all missing or damaged equipment (other than through reasonable wear and tear).

9.2.2.2 Laboratory Equipment

The contractor shall determine if the laboratory testing equipment is adequate to perform all testing required by the contract.

In addition, the following apply:

- The equipment has been checked and calibrated to applicable specifications. It is the contractor's responsibility to ensure the equipment is maintained in proper operating condition.
- No nuclear devices will be furnished.
- The contractor is responsible for providing the laboratory trailer with a water supply and adequate 240-volt, 60-cycle, 200 amp single-phase current for all laboratory electrical needs. A minimum of 60 kilowatts of

power at the entrance box is required for effective use of electrical equipment. Equip the power supply with a regulator that will limit the voltage of the power furnished to not more than 240 volts and not less than 220 volts.

- The contractor shall accept responsibility for the trailer and equipment upon receipt.
- All equipment provided by the Government and replaced by the contractor shall become the property of the Government.
- The rental rate specified in the contract is in effect for the duration of the contract, excluding periods of seasonal or other work shut downs.
- The laboratory shall be used only for testing materials for a specific contract.

Upon completion of the work, the contractor should clean the equipment and trailer. All equipment should be properly stored and secured for the transport of the trailer to the FLH office. Any damage that occurs prior to the trailer being received at the FLH office will be handled according to the contract.

9.2.3 Equipment Calibration

Use only equipment that has been calibrated or verified for the specific test and meets the applicable testing requirements of the contract. Equipment will be calibrated or standardized in accordance with national, FLH Standards, State Highway Agency (SHA), industry standard, or Standard Accreditation Programs.

Prior to the beginning of sampling and testing on a project, the Project Engineer should inspect and document the acceptability of the sampling and testing equipment that will be used on the project.

All necessary equipment should be marked with a tag indicating the date of last inspection, inspector, and calibration number. Checking and monitoring of the equipment during the life of the project should be performed and documented by the contractor to ensure equipment is performing properly.

9.2.4 Equipment Calibration Documentation

The Project Engineer should obtain the following documentation supporting the calibration or verification of all necessary equipment prior to actual sampling and testing. The documentation should be on file.

1. Description of the equipment calibrated or verified, including model number, serial number, or other acceptable identification.
2. Identification of the individual performing the calibration or verification.

3. Identification of the calibration or verification procedure used.
4. Current calibration or verification date and the next due date.
5. Detailed report of calibration results of the work performed, i.e. dimension, mass, force, frequency, temperature, time etc.

The Project Engineer may check equipment to verify condition and calibration. If at any time, it is suspected that the test equipment is not functioning properly or is not calibrated within specification limits the Project Engineer should contact the FLH materials staff to determine what corrective action should be taken.

Under no circumstances should test results obtained using faulty equipment be accepted.

9.3 Contractor's Responsibilities

The contractor is responsible for constructing concrete pavements, structures, and various associated components to the requirements provided in the contract. As part of these requirements, the contractor is to control the quality of the materials provided and the construction process to ensure compliance. The contractor's submitted quality control plan should address sampling, testing, and inspection work that will be accomplished to check and validate the quality of workmanship and material components supplied.

There are various established procedures referenced in the specifications for concrete pavements and structures regarding furnishing products and materials. The contractor needs to follow these procedures to ensure that the material components produced or supplied meet the required specifications; and when combined, the resulting mixture meets the contract specifications. Therefore, the responsibilities for quality cover three general areas; individual supplied material (i.e. cement, aggregate, admixtures, steel, etc.), combined material requirements (i.e. concrete mix design, etc.), and finished product (i.e. placement, curing, strength, etc.). As a general list, the requirements of the contractor include:

- Provide an inspection system for processes and materials quality control.
- Submit and follow the written quality control plan detailing the inspection system.
- Monitor processes to ensure materials provided and work accomplished comply with contract requirements.
- Sample materials to be tested according to the proper sampling method.
- Testing and providing aggregate meeting quality requirements.
- Quality control of aggregate during production to ensure continued compliance with the specifications.

- Proper submittal for mix designs.
- Providing material components and split samples to the Government for verification testing, when requested.
- Monitor construction processes and verify on-site quality and consistency with proper testing.
- Provide appropriate documented test results.
- Provide appropriate certifications (either production or commercial) as established in the contract for supplied material.
- Provide consistent delivery methods for construction (i.e. shotcrete placement, pile driving, drilled shaft construction, etc.)

The contractor needs to provide information and test results according to the timeframes and formats stated in the contract. Distribution of the test reports or certifications should be according to the contract and quality control plan and contain the appropriate information to verify the quality of the material provided.

9.4 Government's Responsibilities

The Project Engineer or designated representative will review the test results and certifications for contract compliance. If clarification or additional expertise is required, the Division Materials Engineer should be contacted.

The Project Engineer or designated representative will also be present to witness all required split samples taken for the Government. In addition, samples that are taken and tested solely by the Government for acceptance, such as concrete strength specimens should be identified in some manner to verify the authenticity. Witnessing and proper sample identification are critical in maintain proper custody of the material samples. Any split samples or samples taken for testing and acceptance by the Government should be secured and immediately be placed in Government control. The Project Engineer needs to be aware of the contractor's operations and be available to witness the sampling, splitting, and testing activities.

As a general list, the responsibilities of the Government include:

- Review the quality control plan for completeness.
- Review aggregate quality test result and/or obtain Government samples for testing.
- Review all material data to ensure compliance with the contract requirements.
- Review and approve submitted mix designs.

- Review test methods, equipment, and protocols with contractor testing personnel.
- Ensure pre-work conferences occur and are attended by appropriate personnel.
- Obtain proper product certifications prior to incorporating material into the work.
- Ensure proper sampling and testing methods are used to evaluate materials and quality during construction.
- Verify proper sampling and testing techniques have been employed at the required frequencies.
- Witness on-site testing of concrete to ensure delivered material is in conformance with the contract.
- Monitor construction processes to ensure material and workmanship conform to contract requirements.
- Review batch tickets to ensure proper mix proportioning.
- Roles and Responsibilities
- Coordinate investigative process for any significant non-compliance issue, in particular low compressive strength concrete.

There are numerous resources available to project personnel to assist in the performance of these tasks. Trade organizations such as ACI, ACPA, and PCA provide excellent technical guidelines and documentation that can help project personnel in the execution of their duties. Additionally, the Division Materials Engineer will provide guidance and assistance to the project should the need arise.

9.5 Materials Certification Acceptance

Proper materials certifications pertaining to each applicable material type and source must be obtained by the Project Engineer and retained in project files. As part of the process for approving a Contractor's mix design, representative certifications should be submitted to the Division Materials Engineer for review and recommendation for approval along with the concrete mix design, form FHWA 1608. The FP requires hydraulic cement production certifications for structural concrete, prestressed concrete, shotcrete and minor concrete. Also, individual materials standards that have been specified in the contract should be referenced. They set forth additional detail pertaining to Contractor submittal of valid manufacturer certifications including required statements, test data and frequency. Certifications must be signed and dated as well as certify that the specified requirements of applicable standards and project specific special contracts requirements have been met. Table 5 summarizes individual concrete materials requiring manufacturer certifications as required in the FP in conjunction with the applicable materials standard to which they must be certified.

Table 5: Required Concrete Material Certifications.

Material	Test Method	Frequency
Hydraulic Cement: Portland Cement Blended Cement	 AASHTO M 85 AASHTO M 240	 1 per shipment 1 per shipment
Mineral Admixtures: Fly Ash Ground granulated blast furnace slag Silica Fume (microsilica)	 AASHTO M 295 AASHTO M 302 AASHTO M 307	 1 per shipment 1 per shipment 1 per shipment
Water	AASHTO M 157	1 for each source
Coloring Agents	ASTM C979	1 per type
Chemical Admixtures: Air-entraining Water-reducing, Set-controlling, Hydration stabilizing	 AASHTO M 154 AASHTO M 194	 1 per shipment 1 per shipment per admixture used

The FP further notes that material accepted by certification may be sampled and tested at any time to verify the properties stated as part of the certification. Sampling of concrete materials should be in accordance with the procedures and sample sizes noted in Table 6.

In general, it is good practice to obtain one sample with each shipment of material. These samples should be retained on the project until final project acceptance or provided to the Division Materials Engineer when required for the purpose of Government testing to verify conformance to the contract specifications.

Table 6: Material Sampling Specifications and Sample Sizes.

Material Component	Test Method	Sample Size
Hydraulic Cement:		
Portland Cement	AASHTO R 71	Representative of not more than 100 tons (90 Mg): Two grab samples at ≥ 10 lb (5 kg) each
Blended Hydraulic Cement	AASHTO R 71	Representative of not more than 100 tons (90 Mg): Two grab samples at ≥ 10 lb (5 kg) each
Mineral Admixtures:		
Fly Ash	ASTM C311	Representative of not more than 400 tons (360 Mg): One grab sample at ≥ 4 lb (2 kg) each
Ground granulated blast-furnace slag	AASHTO M 302	Representative of not more than 125 tons (115 Mg): Two grab samples at ≥ 5 lb (2 kg) each. Remove a 12-in. (300 mm) layer of slag in a hole before sampling.
Silica Fume (microsilica)	AASHTO M 307	Representative of not more than 110 tons (100 Mg): 2 grab samples at ≥ 2 lb (1 kg) each.
Water:	AASHTO M 157	As required for pertinent tests: liquid grab samples at ≥ 1 pt (0.5 L) each.
Compressive strength	AASHTO T 106	
Time of set	AASHTO T 131 ASTM D512	
Chloride as Cl		
Sulfate as SO_4	AASHTO T 290	
Alkalis	AASHTO T 105	
Total Solids	ASTM C1603	
Aggregates (Coarse and Fine)	AASHTO R 90	Coarse Aggregate: 150 lb (75 kg) Fine Aggregate: 100 lb (50 kg)
Aggregate Sample Splitting	AASHTO R 76	Samples are properly split and reduced in size by use of sample splitters or quartering
Chemical Admixtures:		
Air-entraining	AASHTO M 154	Representative of not more than 2500 gal (9500 L): 3 liquid grab samples at ≥ qt (1 L) each Representative of not more than 2 tons (2 metric tons): 4 non-liquid tube samples at ≥ lb (1 kg) each
Water-reducing, Set-controlling	AASHTO M 194	Representative of a unit shipment or a single production lot: 3 liquid grab samples at ≥ 1 pt

		(0.5 L) each Representative of not more than 2 tons (2 Mg): 4 non-liquid tube samples at ≥ 2 lb (1 kg) each

As always, special contract requirements should be reviewed to ascertain if additional materials certifications and samples are required on a project-specific basis.

Appendix A: Form References

Form references for use in the testing of concrete and associated materials.

- Form FHWA 1600C – Request for Laboratory Tests (CFL)
- Form FHWA 1600E – Requests for Laboratory Tests (EFL)
- Form FHWA 1600W – Requests for Laboratory Tests (WFL)
- Form FHWA 1606 – Minor Portland cement concrete mix design trial batch summary
- Form FHWA 1608 – Concrete mix design submittal
- Form FHWA 1621 – Worksheet for sieve analysis of fine and coarse aggregate
- Form FHWA 1627 – Worksheet for sieve analysis of fine and coarse aggregate
- Form FHWA 1638 – Worksheet for determining concrete batch moisture/absorption corrections

FHWA Forms

The most current version of FHWA forms are found at the following website:

https://flh.fhwa.dot.gov/resources/materials/

Documentation and Record-Keeping

Maintain detailed records of all materials certifications, test results, sampling locations and dates, field observations, photographs, and acceptance decisions. These records establish compliance and provide evidence if disputes arise.

For shotcrete, retain test panel results and production concrete test records. For drilled shafts, document slurry conditions, concrete placement procedures, integrity test results, and any corrective actions. For coatings, maintain application records, temperature and humidity logs, DFT measurements, and inspection photographs.

Appendix B: Sample Quantities Guide

Division 500					
	Material / Product	Characteristic	Sampling Method	Minimum Field Sample lbs (kg)	Minimum Split Size to FLH Lab lbs (kg)
Section 501	Aggregate source quality	Coarse aggregate: Alkali-silica Reaction (ASR) and AASHTO M 80 Gradation, AASHTO M 43	AASHTO R 90	—	200 (90)
		Fine aggregate: Alkali-silica Reaction (ASR) and AASHTO M 6 Gradation, AASHTO M 6	AASHTO R 90	—	25 (10)
	Structural concrete	Compressive Strength	AASHTO R 60 and AASHTO T 23	—	1 set of cylinders
Section 502	Aggregate source quality	Coarse aggregate: Alkali-silica Reaction (ASR) and AASHTO M 80 Gradation, AASHTO M 43	AASHTO R 90	—	200 (90)
		Fine aggregate: Alkali-silica Reaction (ASR) and AASHTO M 6 Gradation, AASHTO M 6	AASHTO R 90	—	25 (10)
	Structural concrete	Compressive Strength	AASHTO R 60 and AASHTO T 23	—	1 set of cylinders
Section 552	Aggregate source quality	Coarse aggregate: Alkali-silica Reaction (ASR) and AASHTO M 80 Gradation, AASHTO M 43	AASHTO R 90	—	200 (90)
		Fine aggregate: Alkali-silica Reaction (ASR) and AASHTO M 6 Gradation, AASHTO M 6	AASHTO R 90	—	25 (10)
	Structural concrete	Compressive Strength	AASHTO R 60 and AASHTO T 23	—	1 set of cylinders
Section 553	Prestressed concrete	Compressive Strength	AASHTO R 60 and AASHTO T 23	—	1 set of cylinders
Section 566	Aggregate source quality	Coarse aggregate: Alkali-silica Reaction (ASR) and AASHTO M 80 Gradation, AASHTO M 43	AASHTO R 90	—	200 (90)
		Fine aggregate: Alkali-silica Reaction (ASR) and AASHTO M 6 Gradation, AASHTO M 6	AASHTO R 90	—	25 (10)
	Shotcrete (Production)	Permeable void volume, Boiling absorption, Compressive Strength	AASHTO T 24	—	Cores from production panels

Appendix C: Pre-Drilled Shaft Meeting Agenda

APPENDIX D.3: PRE-DRILLED SHAFT MEETING AGENDA

Pre-Drilled Shaft Meeting Agenda

PROJECT: ______________________________________

DATE: ______________________

1. Construction requirements, review/discuss drilled shaft installation plan
   a. Construction Schedule
   b. Personnel
   c. Equipment

2. Construction Procedures
   a. Excavation, dry/wet methods
      i. Use of casing
      ii. Use of slurry
   b. Vertical alignment of shaft - tolerances
   c. Record keeping during shaft excavation
   d. Cage installation requirements

3. Concrete for Drilled Shafts
   a. Class of concrete—structural or seal
   b. Placement procedure—pumped or free fall
   c. Placement in wet conditions

4. Cross Hole Sonic Logging
   a. Access tube placement
   b. Access tube materials requirements
   c. CSL integrity testing requirements
   d. CSL results and reporting requirements
   e. Interpretation of data
   f. Correction of defects

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